DTU Library

Optimisation of the Danish Energy System in the Light of Externality Costs

Karlsson, Kenneth Bernard; Balyk, Olexandr; Frohn, Lise M.; Brandt, Jørgen; Kaas, Eigil; Baklanov, Alexander; Gross, Allan; Sigsgaard, Torben; Sørensen, Jan; Brønnum-Hansen, Henrik

Publication date:
2009

Optimisation of the Danish Energy System in the Light of Externality Cost

Kenneth Karlsson[a], Olexandr Balyk[a], Lise M. Frohn[b], Jørgen Brandt[b], Eigil Kaas[c], Alexander Baklanov[d], Allan Gross[d], Torben Sigsgaard[e], Jan Sørensen[f], Henrik Brønnum-Hansen[g]

[a] Risø DTU National Laboratory for Sustainable Energy,Technical University Denmark, Roskilde, Denmark
[b]National Environmental Research Institute, Aarhus University, Roskilde, Denmark
[c] Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[d]Danish Metrological Institute, Copenhagen, Denmark
[e] Institute of Public Health, University of Aarhus, Aarhus, Denmark
[f] University of Southern Denmark, Odense, Denmark
[g] National Institute of Public Health, Copenhagen, Denmark

Corresponding author: "Kenneth Karlsson" <keka@risoe.dtu.dk>

ABSTRACT

Fossil fuel related air pollution influences both the natural environment and human health. The particle pollution from cars and trucks alone is considered to cause more deaths than traffic accidents. This has lead to the establishment of a Danish Centre of Energy, Environment and Health (CEEH) [1] which is supported by the Program Commission for Energy and Environment under the Danish Council for Strategic Research. The objective of CEEH is to establish an interdisciplinary based system to support optimal future planning of energy production and usage with respect to costs related to the natural environment and human health. To ensure the needed interdisciplinary approach the centre includes researchers from meteorology, air pollution, environment, energy, physiology/health and economy. The main planned outcome of the centre is an integrated regional economic model system including components for air pollution chemistry and dispersion down to urban and sub-urban scales, and model components of the impacts on public health and the external environment.

The current piece presents the first results obtained within the collaboration in the Centre for Energy, Environment and Health with respect to optimisation of the future Danish energy system. They build upon the outcomes of the investigation carried out within the centre aiming at monetisation of the impacts from emissions on the Danish society and clearly illustrate the significant effect inclusion of externality costs may have on the development of the Danish heat and power sector.

Danish District Heat and Power Sector and its Impact on the Welfare of Danish Society
Danish district heat and power demand is satisfied from a variety of sources. In 2007, about 70% of the district heat and power generated by the sector was coming from the traditional fossil fuels (natural gas, coal, and oil) and non-renewable waste (DEA 2008). The remaining part was shared between biomass (64%), wind (33%), and other renewable energy sources. Heat and power production in Denmark have remained relatively stable over the last two

[1] www.ceeh.dk

decades, with a general trend of increasing the share of energy generated from renewable sources.

Energy generation by the heat and power sector brings along emissions of harmful substances leading to the climate change, acidification, adverse health effects (e.g. increased mortality or morbidity) etc. Among the causes of these are CO_2, SO_2, NO_x and PM. The share attributed to the Danish district heat and power sector in the total emissions in Denmark varies depending on the pollutant and in 2006 was 51%, 41%, 28%, and 3% respectively (NERI 2008). The emissions come either from fossil fuel or biomass burning.

Over the last decade the emissions in Denmark have been staidly declining. As a result of successful policies, emissions of SO_2 dropped from 171 kt in 1996 to 25 kt in 2006; a similar trend was observed in NO_x – a reduction from over 304 kt in 1996 to about 185 kt in 2006. However, some preliminary estimates of the external effects from the non-carbon emissions on the human heath predict the impact of the Danish heat and power sector alone to be in the order of billions DKK.

Methodology

A key element of the CEEH is to expand, evaluate and apply integrated models for all impact pathways, including integrated energy systems, emissions, atmospheric chemistry/transport, human exposure, human health models as well as cost models. This chain of models is necessary to optimise the energy production system from a grand economical viewpoint, and will be used to provide qualified guidelines for all sectors of the future energy planning in Denmark. When implementing cost estimates of pollution damage (externalities) from energy production and consumption it is possible to determine the cost effectiveness of air pollution, health effect prevention, mitigation methodologies / technologies, or to compare and optimise the total energy cost options for the society.

At this stage and for the purpose of the current study only a part of the future modelling system is applied. Estimates of the cost of emission of SO_2, NO_x, PM2.5 and CO are taken as a basis for optimisation of the future energy system. Additionally, different levels of the CO_2 price are assumed. The optimisation of the energy system is carried out by means of Balmorel[2] the energy system model used in the CEEH modelling framework which includes the Danish heat and power sector and surrounding countries.

The Balmorel model is a linear optimisation model of a power and heat system with perfect competition. Based on scenarios for the development in input parameters such as fuel prices or technology data, the model calculates the operation of the units in the power system and the new investments in power plants and transmission lines that maximise social surplus in the power system. The model is multi-regional consisting of regions connected by transmission lines. It takes into account the balance between supply including net export and demand in each region, capacity restrictions for production units and transmission lines, technical restrictions for CHP plants, balance equations for heat, and hydropower. The

[2] www.balmorel.com

externality costs have been integrated into the objective function in order to take these into account in the optimisation process.

Preliminary Results

The results of the optimisation process by means of Balmorel with respect to the investments in new technologies (Table 1) up till year 2030 are show in Fig.1. The various runs differ according to the assumptions used: no inclusion of any externalities in Run1, different CO_2 prices (10, 25, and 50 EUR/tonne) in runs 2 to 4 together with constant prices for other pollutants, no CO_2 charge in Run5, and only CO_2 charge of 50 EUR/tonne in Run6. All of them are based on the same fuel prices from WEO 2007 (IEA 2007).

Table 1 Overview of the combination of CO2 price and inclusion of externalities in the model runs.

	Run1	Run2	Run3	Run4	Run5	Run6
Externalities	No	Yes	Yes	Yes	Yes	No
CO2-price (€/tonCO2)	0	10	25	50	0	50

One can see how different technologies are favoured depending on the degree to which externalities are included and the corresponding price. For example, Run1 and Run5 (both do not include any CO_2 charge) contain investments in the coal-based technologies, but not wind. However, directly the opposite is valid whenever the CO_2 charge is in place. In Run6, which is characterised by the highest externality charges even the expensive Carbon Capture and Storage technology is introduced.

Comparison between the annual cost of the technologies for CO_2 price of 25 EUR/tonne and 50 EUR/tonne is given in Fig.4 and Fig.3 respectively. This is a good illustration for explanation of why the model chooses to invest differently when externality charges are present contrary to the situation when they are not in place. However, the higher fuel prices and CO2 price the less influence externalities have on the result.

Emissions of CO_2 differ dramatically depending on the run (see Fig.2). The minimum value achieved in the Run4 is approximately 35 times lower than the maximum observed in the Run1. Even though, no charge was applied for the CO_2 emission in the Run5, its level is considerably lower than in the worst case.

Table 2 – Technologies in which investments are allowed.

Technology	Description	Efficiency	Variable Costs (EUR/MWh)	Fixed Costs (kEUR/MW)	Investment Cost (MEUR/MW)
CC-NG-ENS	Combined cycle nat. gas power plant	58%	0.46	12.50	2.20
COAL-CCS	Coal power plant with CCS	42%	4.80	18.20	1.70
HO-B0-NG	Heat boiler on natural gas	95%	0.67	0.54	0.05
NU-C0-NU	Nuclear power plant	35%	2.20	0	70.00
OC-ADGT-NG	Open cycle natural gas turbine	43%	2.00	32.00	0.50

ST-Biomass-ENS	Biomass power plant	43%	3.10	28.50	1.50
ST-Coal-ENS	Super critical steam coal power plant	48%	2.00	18.20	1.40
WI-offshore-ENS-2	Offshore wind turbine	100%	4.00	18.00	1.40
WI-onshore-ENS-2	Onshore wind turbine	100%	0	15.00	0.80
EH-P9	Heat pump	260%	1.27	3.03	0.32

Even with a CO2 price at 25 €/tonCO2 Figure 1 shows that there is no investments in coal power, but in wind power and gas. Together with the investments in wind power there is also invested in central heat pumps to level out fluctuating power production and to increase flexibility in the district heat and power system. With the high CO2 price in run6 coal power with CCS enters on behalf of gas and wind. The pure impact of the externalities can be seen by comparing investments in run1 and run5.

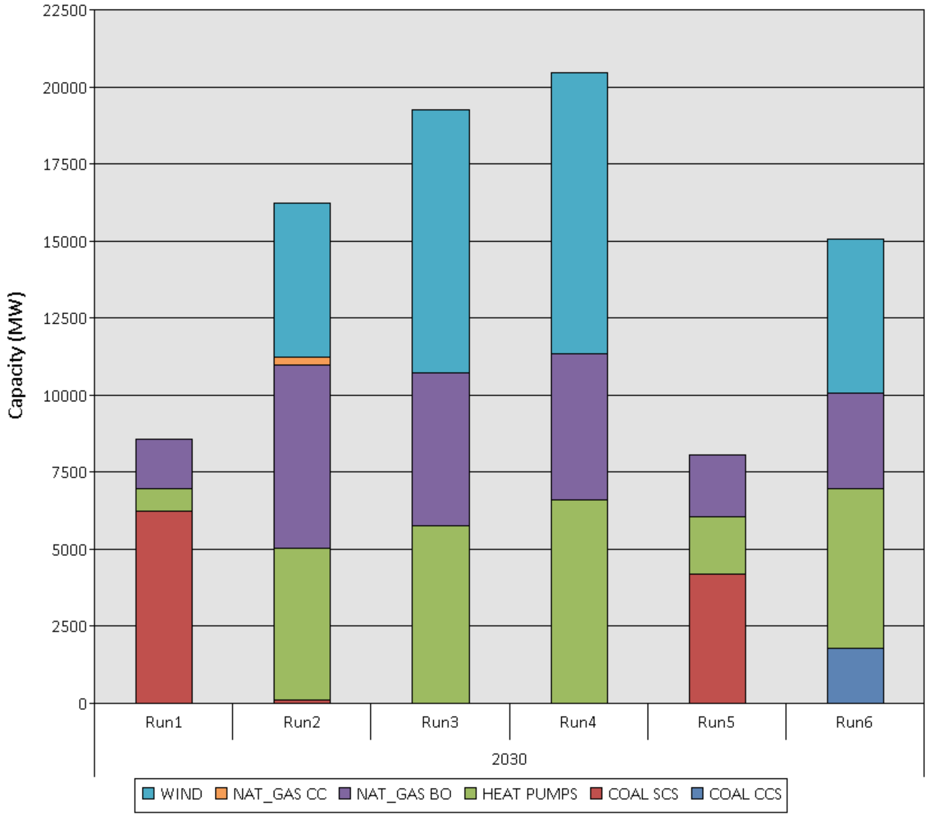

Figure 1 – Heat and power generation capacity added during the simulation year.

These differences in investments leads to very different emissions of different spices e.g. CO2 as shown in Figure 2.

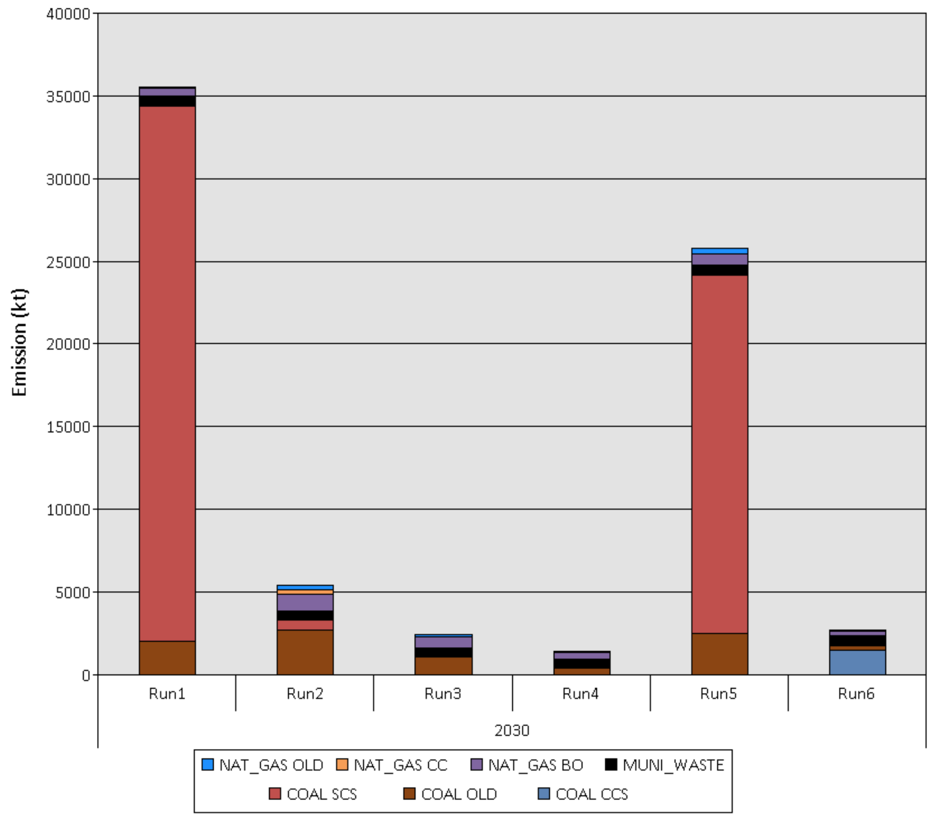

Figure 2 – CO2 emissions from the heat and power generation in the simulation year from different fuels.

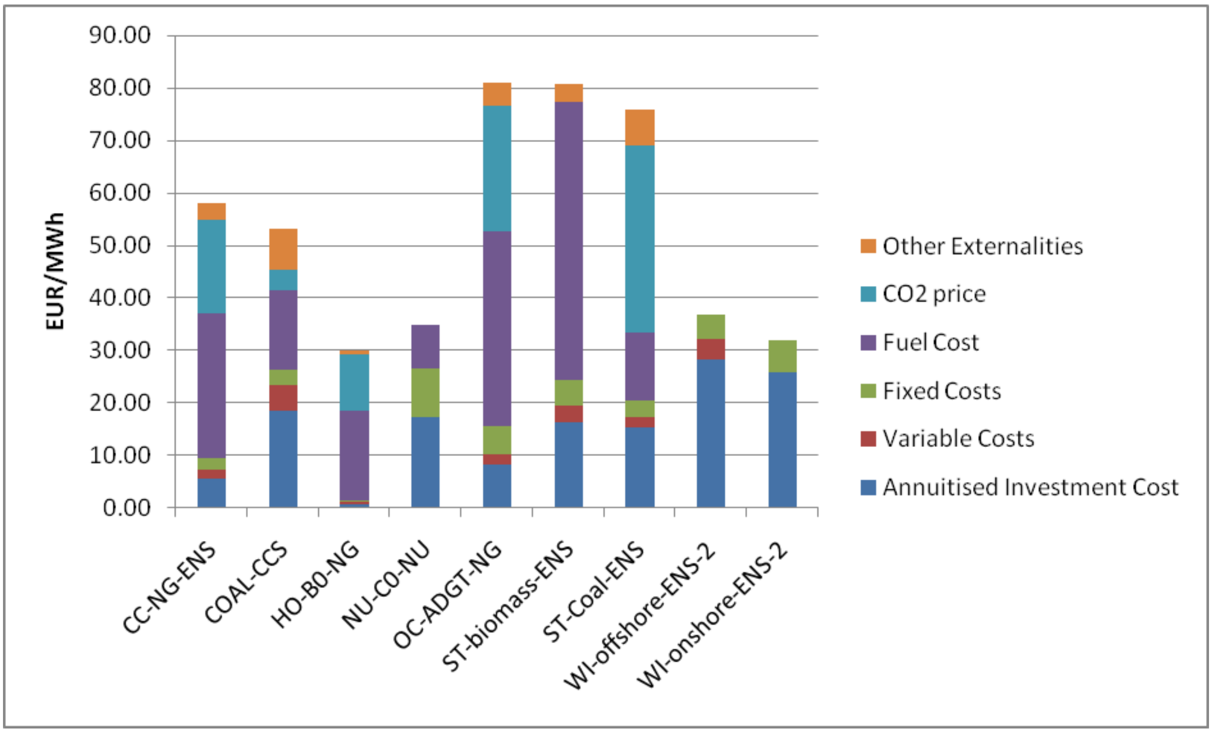

Figure 3 - Competitiveness of the possible investment technologies at the CO_2 price of 50 EUR/tonne.

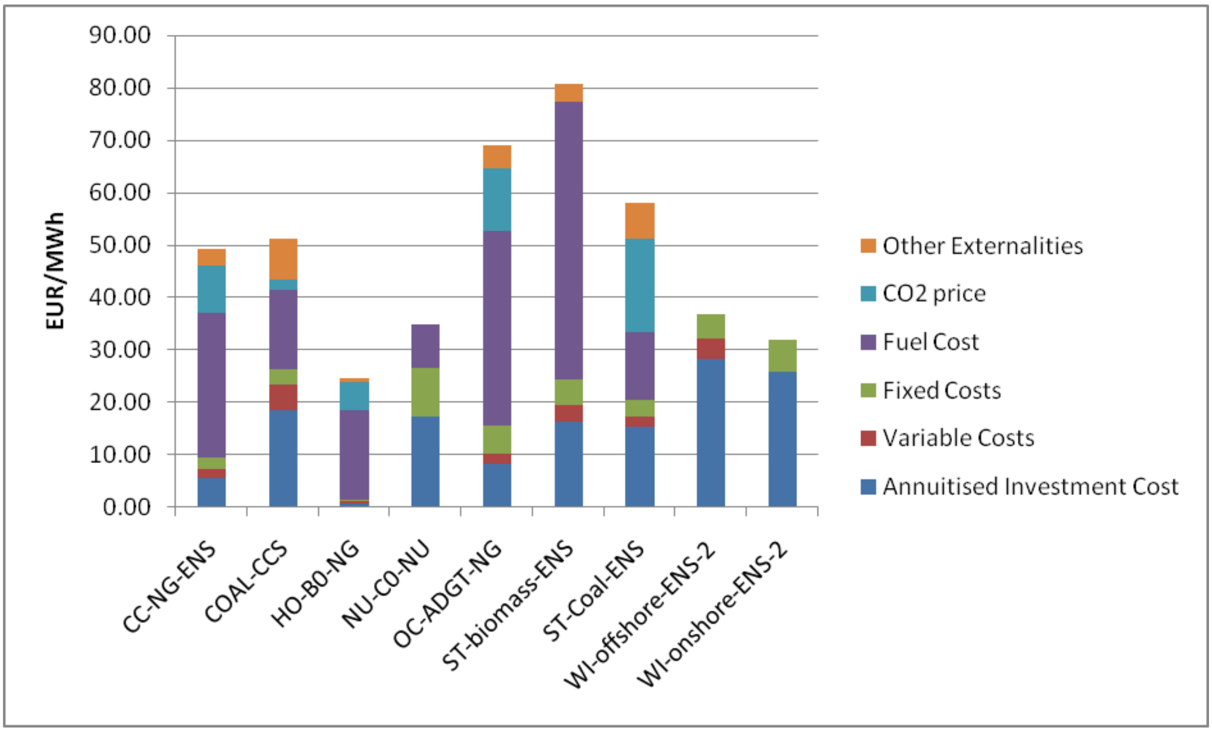

Figure 4 - Competitiveness of the possible investment technologies at the CO_2 price of 25 EUR/tonne.

Acknowledgement

The present study is a part of the research of the 'Center for Energy, Environment and Health'', financed by The Danish Strategic Research Program on Sustainable Energy under contract no 2104-06-0027.

References

Danish Energy Agency (DEA). 2008. *Energy Statistics 2007.* Copenhagen: DEA.

International Energy Agency (IEA). 2007. *World Energy Outlook 2007: China and India Insights*. Paris: OECD.

National Environmental Research Institute (NERI). 2007. *Air Pollutants*.
URL: http://www.dmu.dk/Luft/Emissioner/Air+pollutants/ [accessed on 26.02.2009]